HAYS & THVEDT

Design and Performance of Magnets in the Automatic Telephone

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DESIGN AND PERFORMANCE OF MAGNETS IN THE AUTOMATIC TELEPHONE

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

DON LLEWELYN HAYS AND CHRISTIAN BERNHARD THVEDT

ENTITLED DESIGN AND PERFORMANCE OF

MAGNETS IN THE AUTOMATIC TELEPHONE

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING

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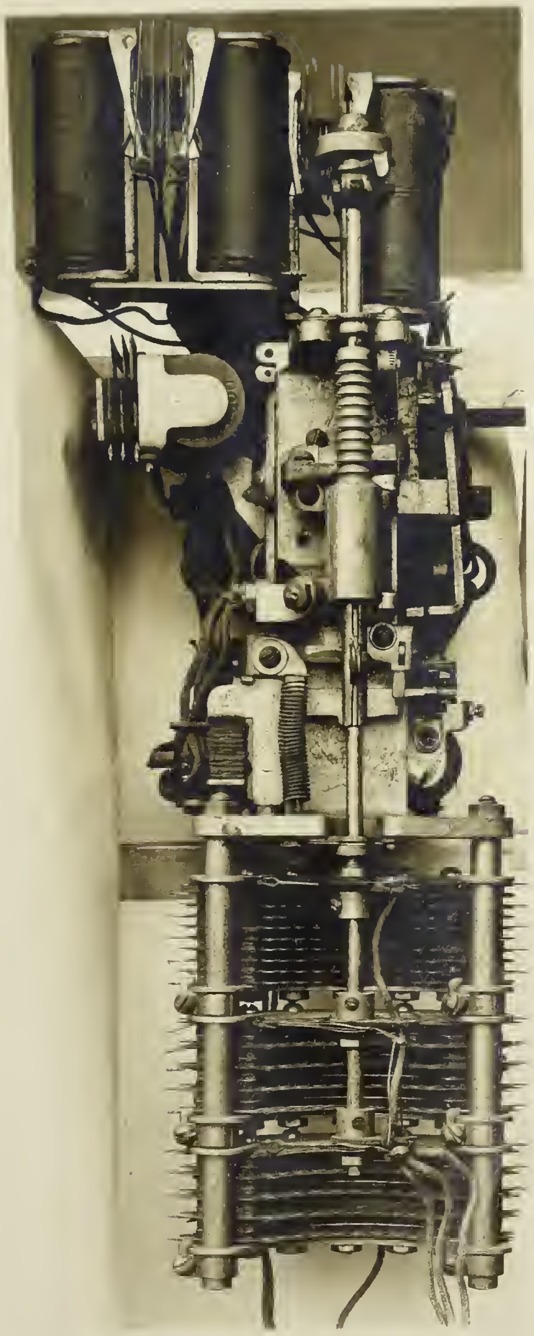

The Automatic Telephone Switch.

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THE DESIGN AND PERFORMANCE OF MAGNETS IN THE AUTOMATIC TELEPHONE.

OBJECT: To study and test magnets used in the automatic telephone, and to investigate means of probable improvement in the same.

INTRODUCTION.

In perhaps no electrical device has the electromagnet become so important or achieved such an extensive application as in the modern automatic telephone. While the development of the automatic telephone switch operated by electromagnets has extended over a period of some twenty or twenty-five years, yet comparatively little effort has been directed toward ascertaining the proper design of magnets most effective and efficient in telephone operation.

The most up-to-date automatic telephone switch now in use has six sets of magnets each set of which has a certain function to perform in the operation of the switch. The principal feature, however, in such operation is the attractive force exerted on a movable armature by the magnet. Hence, in order to ascertain the most effective design of magnets for such use described, this test and study is mainly concerned with this attractive force and its effect in producing desired results.

PART I. Design of Magnets in the Automatic Telephone Switch.

In general there are two classes of magnets used in the operation of the automatic telephone switch; rapid acting and slow acting magnets. Of these perhaps the rapid acting magnets perform the most important function, and hence will receive most attention.

The requirements for the proper working of such magnets are varied and may be stated under the following general heads:-

(1) Rapidity of action in response to a completed circuit.

(2) Ability to exert a high degree of attractive force for a given current in a brief period of time.

(3) Ability to quickly release upon breaking of the circuit.

(4) Such design of magnets as to reduce the sparking at contact points in the circuit so far as possible.

For rapid action it becomes at once apparent that the magnet in use should possess but small residual magnetism and hence should preferably be made of pure Swedish iron well annealed. Its form should be that of a short bar in order that the ends or poles of the magnet may exert a demagnetizing force upon the mass of the interior and thus quickly rid the magnet of residual magnetism. Where slow action is required, however, the core should be long and thus allow the residual magnetism present to be uneffected by the neutralizing action of the ends of the magnet.

Sluggishness of action, as is sometime desired, may be also increased by placing a copper or brass sleeve over the core.

Rapidity of action, on the other hand, is also dependent to a great extent on the number of turns and the nature of core used.

An increase in the number of turns increases the inductance produced as the current builds up or dies down, and this in turn increases the time of energizing and also the time of demagnetizing which is enhanced by the use of a solid core. It is clear that high inductance effect will be increased and hence should be avoided in the design of rapidly acting magnets.

In the design of magnets, it is well to keep in mind the following:-

(1) Shape of magnet,

(2) Quality of Iron used in core.

(3) Reluctance of Armature operated by the magnet.

(4) Magnetic Leakage.

In order that a minimum number of lines of force be lost due to leakage, it would seem of advantage to shape the magnet somewhat according to the form assumed by the lines of force themselves. This form is that of a circle (See Fig. 1a&b) Sharp turns and edges should therefore be avoided.

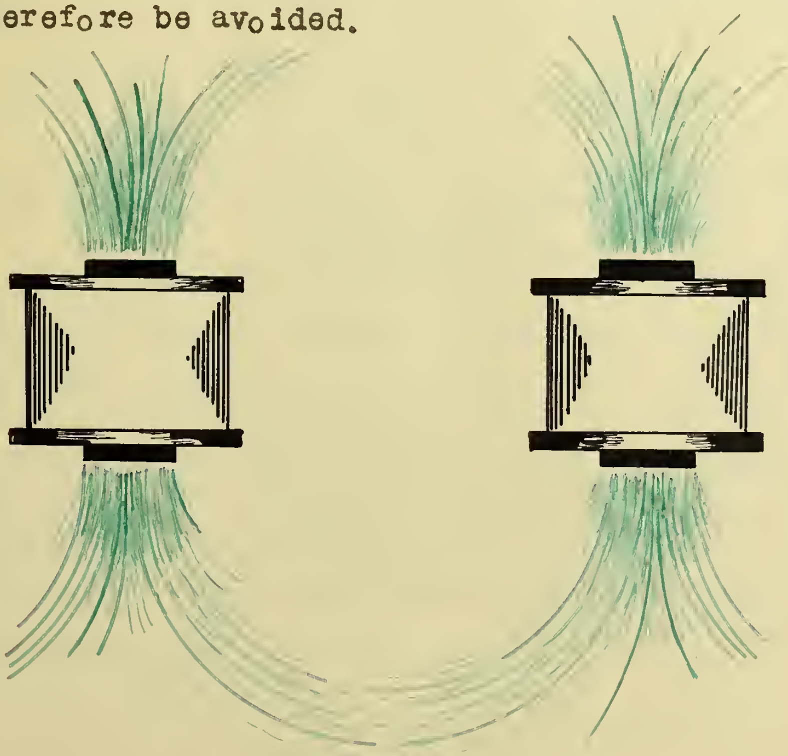


Figure 1a

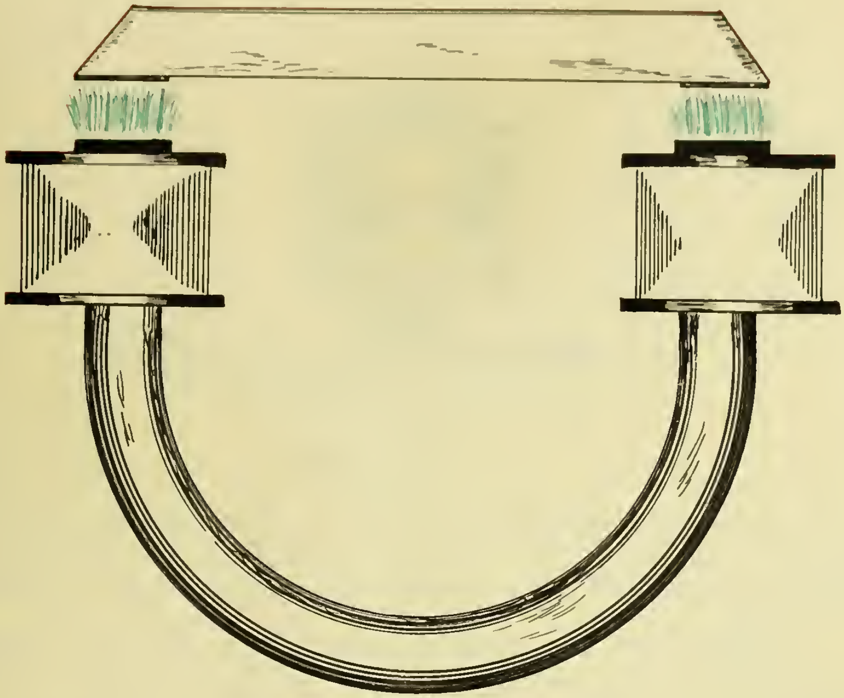


Figure 1b.

Since it is of advantage to reduce the reluctance due to the air gap as far as possible, the shape of core and armature is of importance. The reluctance of air being taken as unity, we have

$$(1) \qquad R = \frac{l}{A\mu}$$

where R = Reluctance of Magnetic Path.
l = Length of Magnetic Path.
A = Sectional Area of Path.
μ = Permeability of substance comprising path.

From equation (1) it may be seen that an increase in cross sectional area "A" reduces reluctance "R". Thus if the core be counter-sunk and the part of the armature in line with the core be tapered as shown in Figure 2, it is clear that for a given magnet an increased attractive force will be produced due to the increased sectional area.

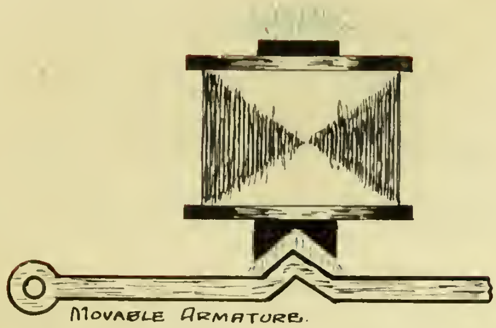


Figure 2

The quality of iron is of importance as shown by permeablity "μ", the lines of force being greater the better the path. This is evidently true for the armature as well as the magnet.

Since magnetic leakage tends to decrease the strength of a magnet, it is to be reckoned with in the design of magnets. If the form of the magnet be U shaped, by putting the legs of the U closer together the magnetic leakage will be increased since the path thru the air is shortened. But, considering the path in the armature, by increasing the air gap between the two U's also increases the percentage of leakage, for the reluctance of the path must necessarily increase with the length of path. Hence there must be some limiting position of the legs of the U shaped magnet which will allow the least magnetic leakage. This position will of course depend upon the nature of the armature and core used, and can readily be determined experimentally for any given magnet by using a U shaped one, the legs of which may be moved to any desired position relative to each other. This position, however, would not be fixed for any given value of excitation. It must be remembered that the saturation curve of iron, which is used in such armatures as well as in cores, is not a straight line, and that the re-

luctance of the useful path increases with the increase of excitation. Thus with low degree of saturation (reluctance of useful path being small) the legs of the magnet should be placed farther apart than with a high degree of saturation. Hence, for compactness and effectiveness, a comparatively high excitation would be preferred.

In the design of magnets it is further important to locate as far as possible the path of the leakage flux. In this way the forms, the magnet may be adjusted to,give the proper path to the lines of force which otherwise would have been lost by leakage. A study of the distribution of the leakage flux may be made by means of a small magnetic needle suspended by a silk thread. The direction assumed by the needle would give the direction of the leakage flux.

In the automatic telephone where innumerable contacts are used for make and break, sparking becomes a factor of considerable import. Vicious sparking is largely due to inductance. If an electro-magnet is connected in a circuit, inductance tends,as the circuit is breaking, to increase the E.M.F. in full thus causing current to be maintained across the break. This may be explained by a study of the nature of inductance. It occurs upon a variation in excitation,a voltage being set up due to this change in flux cutting the turns of wire.

Sparking may be reduced in several ways. It may be done by condenser action, or by the differential method, or by various other methods not discussed here. While condensers may be used to reduce or eliminate sparking, it is not practical economically as such a high capacity would be required to supply an entire telephone exchange.

The differential method consists in winding a coil in parallel with the winding of the electro-magnet thus forming two distinct windings insulated from each other and lying side by side in every turn of the winding. The two terminals of the auxiliary winding are then connected together thus short circuiting the winding upon itself. If now a current be suddenly passed thru the exciting coil, a momentary opposing current will also flow in the auxiliary coil. The inductance of the auxiliary coil will thus tend to neutralize that of the other and hence eliminate sparking. The auxiliary coil need not have as many turns as the exciting coil of the magnet, but would nevertheless reduce sparking considerably. The extra expense involved would not be very great, and it might be of value to adopt some such method in the installation of a commercial telephone exchange.

In the automatic telephone switch the percentage of make and break is about 50, that is, by closing the electrical circuit and putting the magnets into operation, the time of attraction of the armature by the magnets and the time of release of the same is about the same. The ratio of make to break is of importance in the economical and effective working of the switch. If the time during which the circuit is made is only, say 10% and that for which it is broken is ninety percent, then it is found that the clutches lifting the shaft do not have time to operate and therefore prevent the switch from doing its duty. If now the percent of make to break is made ninety percent to ten percent of break, then, too, it is found that the switch will not work. This, to a great extent, is due to to the residual magnetism of the core of the magnets. Provided that the operation of the switch is satis-

factory, however, it would seem preferable and more economical to adjust for a shorter period of make than of break in order to economize in the use of power. The limiting time of make would in in any case depend upon a number of factors, and for any given set of magnets would have to be found experimentally.

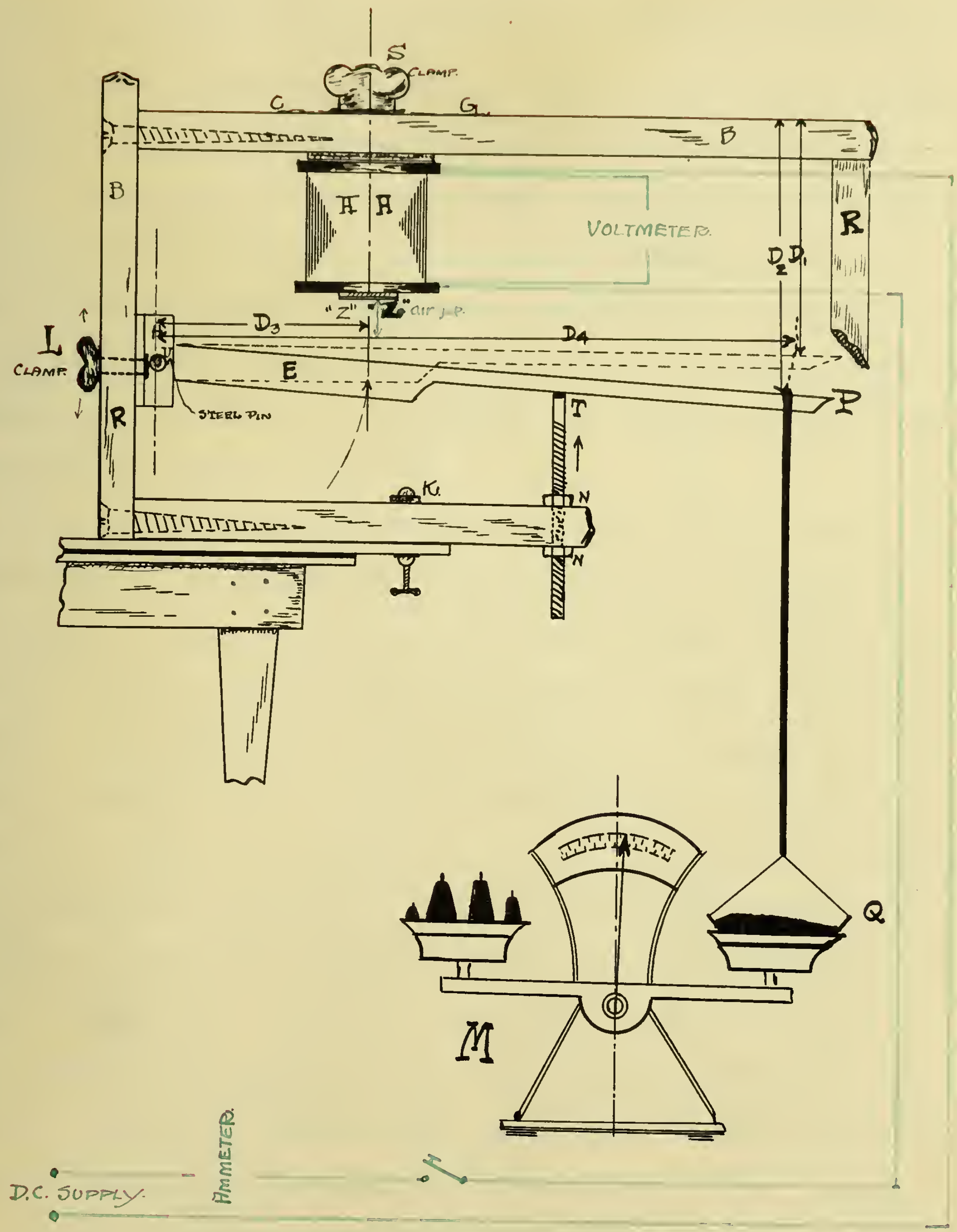


Figure 3.

Electrical Connections(Green)

"L" thumb screws for adjusting armature to any desired height for various sizes of magnets.

"M" Balance Scales with which to weigh pan and contents.

"K" Clamp to hold frame firmly to table or bench.

"T" Screw which threads with nuts "N" to adjust length of air gap "z".

PART II. Tests on Electro-Magnets in Automatic Telephone Switch

As has been mentioned before, the most up-to-date automatic telephone switch contains six separate sets of magnets. In an effort to determine the various actions characterizing the performance of the electro-magnets in the automatic telephone switch, tests were made, first, to learn as accurately as possible the lifting power of a set of magnets for various values of current passing thru the coil conductors; and second, to ascertain the power exerted by the magnets for various lengths of air gap.

In order to determine effectively the lifting power of magnets under varying conditions of voltage, current, and length of air gap, a suitable device had to be constructed by means of which the power of the magnets could be accurately noted for such conditions. This device was constructed as shown in Fig.3. AA represent a set of electro-magnets held to frame B and adjustable along CG by the thumb screws S. The iron armature E moves in the direction indicated by the dotted arrow under the influence of the magnetized coils. In the automatic switch, this armature lifts the selector or connector shaft at point P. Instead of using the shaft in testing the lifting power of the magnets, a pan Q was suspended from the armature at point P into which weights could be placed. Supports RR were necessary to sustain the strain upon B when the pan Q was loaded.

Air gap "z" was determined by measuring D_1 and D_2 by three inch micrometer calipers, and lengths D_3 and D_4 by finely calipered scales. Air gap "z" was adjusted to any desired value by means of the thumb screw T which engaged nut N in the lower part of the frame.

As outlined in Figure 3 and as just described, this device per-

mitted the measurement of the lifting power of the magnets by the measurement of the torque exerted upon the lever UP (Figs.3 and 4) By placing weights upon the pan of such amount as to enable the magnets to barely lift the armature with its load, and then weighing the total (armature and pan together with the weights upon the pan) accurately upon the scales, the lift of the magnets under various conditions was readily determined.

Figure 4 shows three views of a standard vertical magnet armature. Such armatures are made of No.9 (Brown and Sharpe)Norway iron annealed, having a thickness of .114 inch. The armature, as is shown to a certain extent in Figure 3, moves about a round steel pin O as a fulcrum. This pin fits closely into drilled holes in wings of the armature as shown in Figure 4b.

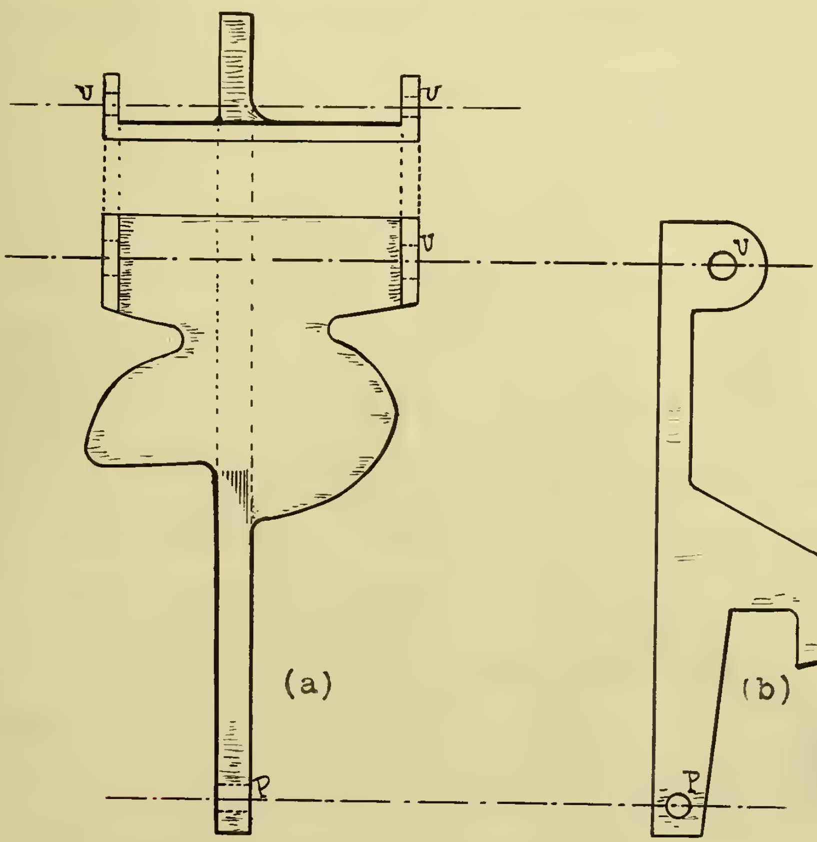


Figure 4.

First among the tests made was that to determine the lifting power of the magnets for various values of current. The results of this test are shown in tabulated form on page and graphically in the form of a curve on page 16 (See Graph No.1)

Under usual conditions of operation of automatic telephone switch magnets, the current is limited by the voltage employed. This is neccessary owing to the magnets being wound with such size wire as to conveniently carry a certain maximum current for a time without overheating and possibly destroying the magnets. In obtaining data on page 15 the magnet coils were found to heat very rapidly when the higher values of current were used. Graph No.1 shows that more current is required proportionally to the weight lifted for smaller than for larger weights. This is to be expected when it is remembered that the inertia of the weights, pan and armature must be overcome. A second cause for a proportionally greater current to lift the smaller weights upon the pan is that the friction of the armature upon the steel pin is greater at first. After overcoming the inertia and friction, much less current compared to the weight lifted by the magnets is required for additional weight.

Subjecting the magnets to more usual and normal conditions, a test of the lifting power with variable air gap and constant currant at all times was made. This value of current was that normally flowing thru the magnets when in operation on an automatic telephone system. Graph No.2, plotted from data on page 17 shows the results obtained from the test. From the curve, it is seen that the lifting power of the magnet is not decreasing in a direct proportion to the increase of air gap as might be expected. The magnets used seem to have reached their useful limit of attraction with the normal

current flowing for a gap about .093 inch. in length. That is, supposing that an armature of zero weight were acted upon by the magnets under the given conditions, the armature would not be moved by the magnets until the length of air gap was cut down to .093 inch. To increase the current, as was done in the previous test(graph No1) and, as has been previously stated, is not permissible for the safety of the magnet coils. This may be better realized when it is remembered that an ordinary telephone exchange contains thousands of such magnets, and that a current of high value for only a few moments might not only mean the loss of many magnets but the tying up of the system.

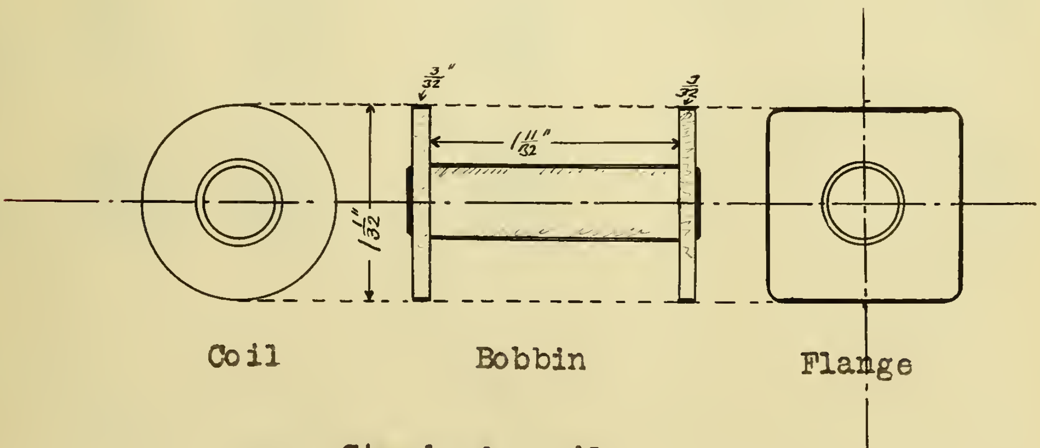
To determine the time of make and break referred to on page 7 as well as the ratio of the two, a chronograph was used in connection with the vertical set of magnets previously described in the operation of the shaft(See Figure 3).

The data obtained concerning the time of make and break was taken with the switch properly adjusted. Referring to the chronograph record (Figure 6) the distance between breaks in the blue lines represent a period of time of one second. The small waves on the red lines, on the other hand, are those for make and break of the switch. As nearly as can be determined from the waves, it seems that the periods of make and break are equal. The actual duration of any such period may be found by noting the distance between the breaks in the blue lines by means of a scale or compass. The same measurement is made in the breaks in the red line. The ratio between the two will give the period of make and break in terms of a fraction of a second.

Referring to Figure 6 and considering the red line "A", the length of the three waves marked is found to be 0.55 inch. The

length between breaks on the blue line is found to be 2.02 inches, and the ratio between the two is 0.272 thus showing the time represented by a single wave to be one third of this or one-eleventh of a second.

The inductance of a set of electro-magnets as shown by diagram (See Figure 5) was measured according to Anderson's modification of Maxwell's method of measuring inductance. An alternating current galvanometer was used in connection with this measurement. The inductance of the coils was found to = .375 henry.

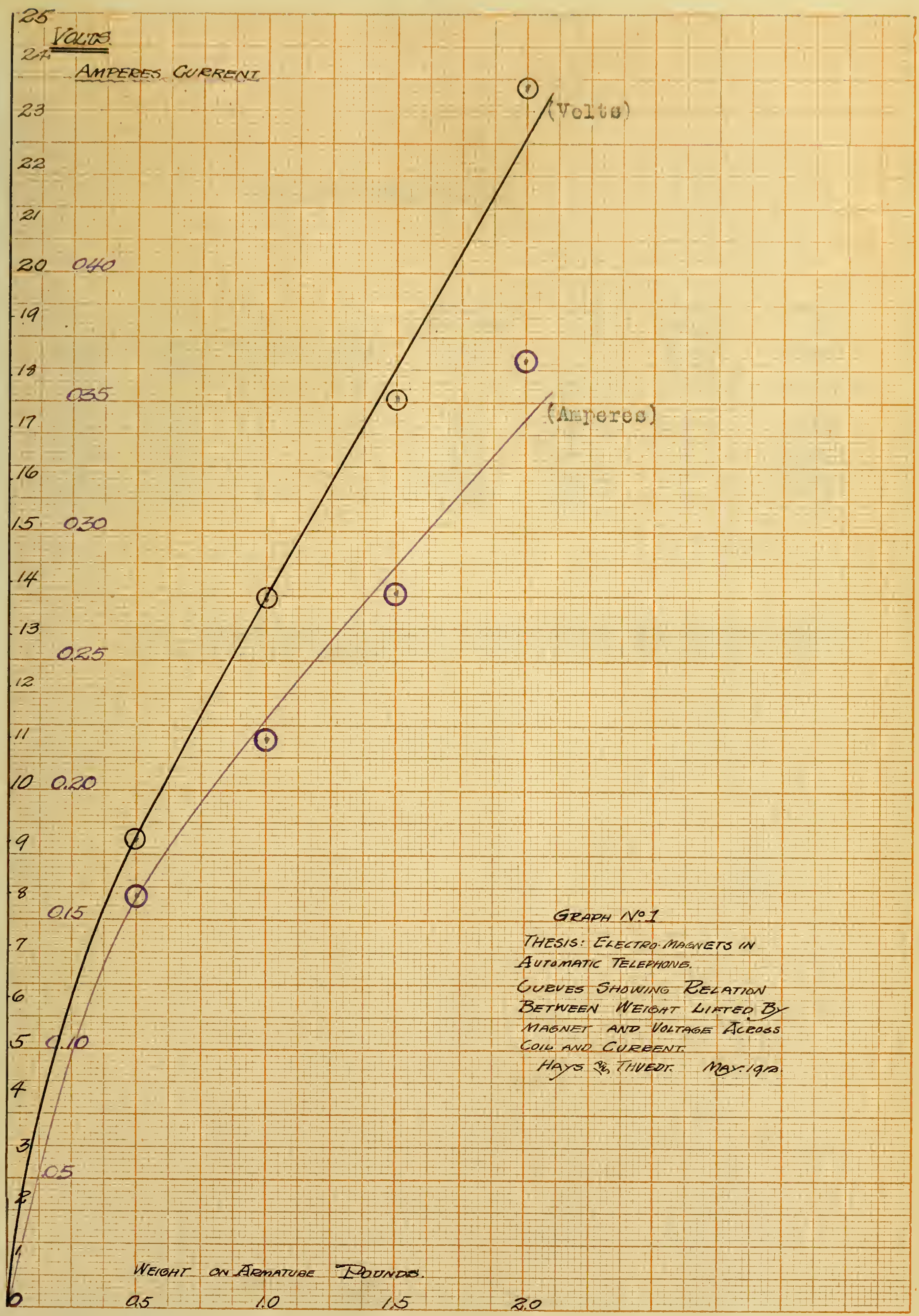


Standard coil.

DATA FOR GRAPH No. 1.

	E_o	e	I(amps)	Wt.(gr)	Lever Arm (inch) Fig.3 "HD"
	66.0	9.00	0.170	0.50	2.75
	72.5	9.10	0.170	"	"
	70.0	9.30	0.155	"	"
	69.9	8.90	0.150	"	"
	69.5	9.00	0.150	"	"
Average--	69.58	9.06	0.159	"	"
	64.0	13.50	0.220	1.00	2.75
	62.9	13.90	0.220	"	"
	54.0	13.90	0.220	"	"
Average--	60.30	13.77	0.220	"	"
	61.0	17.90	0.280	1.50	2.75
	60.0	17.00	0.270	"	"
	60.5	17.90	0.280	"	"
Average--	60.50	17.60	0.277	"	"
	57.9	23.70	0.370	2.00	2.75
	60.0	23.00	0.370	"	"
	60.8	23.80	0.360	"	"
Average--	59.57	23.50	0.367	"	"

(See Diagram No.3)


Volts
Amperes Current
25
24
23
22
21
20 0.40
19
18
0.35
17
16
15 0.30
14
13
0.25
12
11
10 0.20
9
8
0.15
7
6
5 0.10
4
3
0.5
2
1
0
0.5
1.0
1.5
2.0
Weight on Armature Pounds.
(Volts)
(Amperes)
Graph No 1
Thesis: Electro-Magnets in Automatic Telephone.
Curves Showing Relation Between Weight Lifted By Magnet and Voltage Across Coil and Current.
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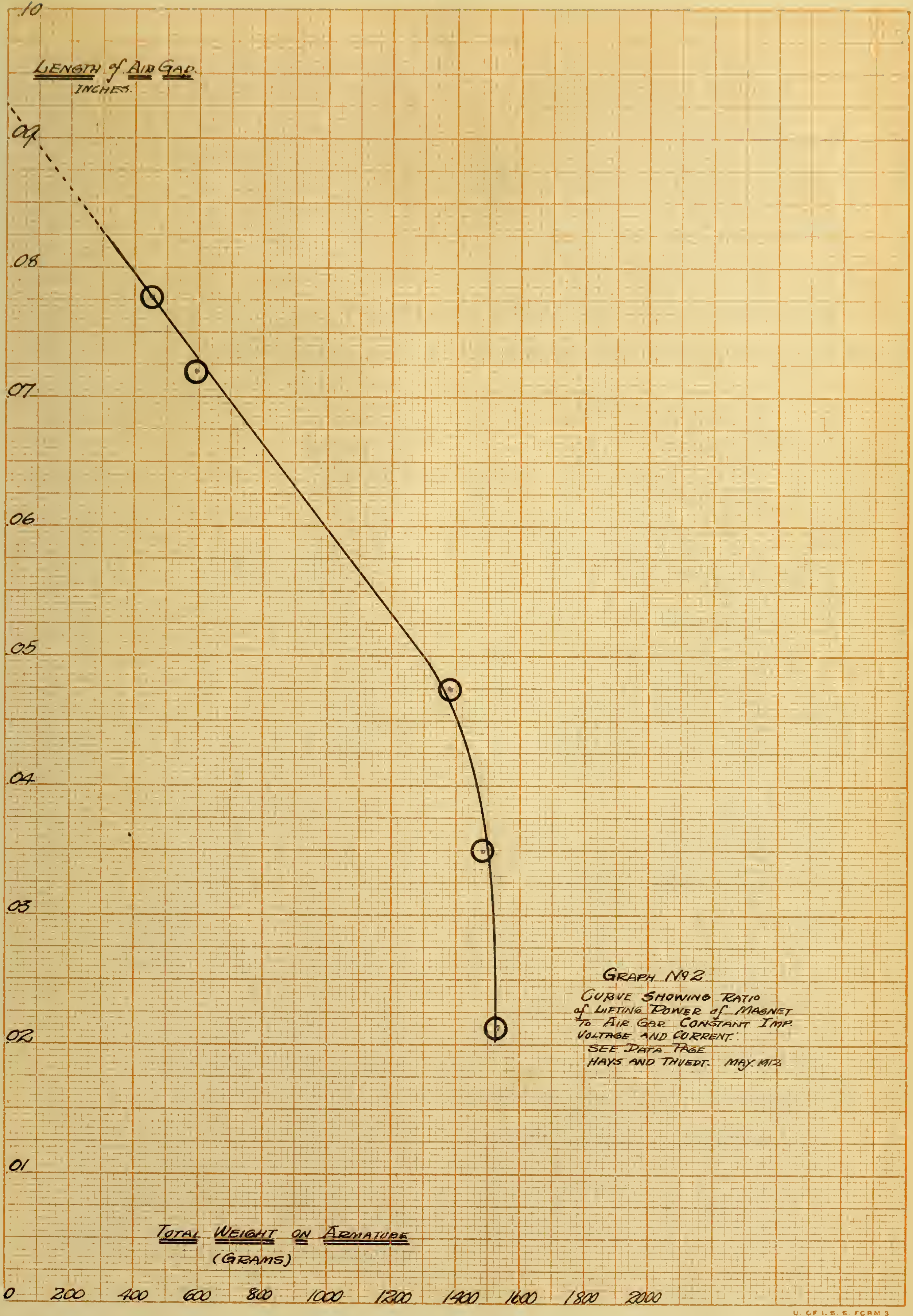
DATA FOR GRAPH No.2.

D_1 (Inch) "XY"	D_2 (Inch) "XM"	D_3 (Inch) "HJ"	D_4 (Inch) "HD"	Length of Air Gap (Inch) "z"	Wt. in Grams	Volt. Across Mags. Volts	Cur. I in Amps.
2.546	2.672	0.750	2.750	0.0350	1482.2	47.0	0.78
2.651	2.728	"	"	0.0214	1531.0	"	0.76
2.546	2.690	"	"	0.0500	1381.0	"	0.78
2.600	2.8596	"	"	0.0720	598.2	"	0.78
2.634	2.913	"	"	0.0776	448.0	"	0.76

(For explanation of above nomenolature see Diagram Fig.3
Note: Letters marked thus "x" refer to Figure 3)


.10
LENGTH of AIR GAP.
INCHES.
.09
.08
.07
.06
.05
.04
.03
.02
.01
0
200
400
600
800
1000
1200
1400
1600
1800
2000
TOTAL WEIGHT ON ARMATURE
(GRAMS)
GRAPH Nº2
CURVE SHOWING RATIO
of LIFTING POWER of MAGNET
TO AIR GAP. CONSTANT IMP.
VOLTAGE AND CURRENT.
SEE DATA PAGE
HAYS AND THVEDT. MAY 1912.
U. OF I. S. S. FORM 3

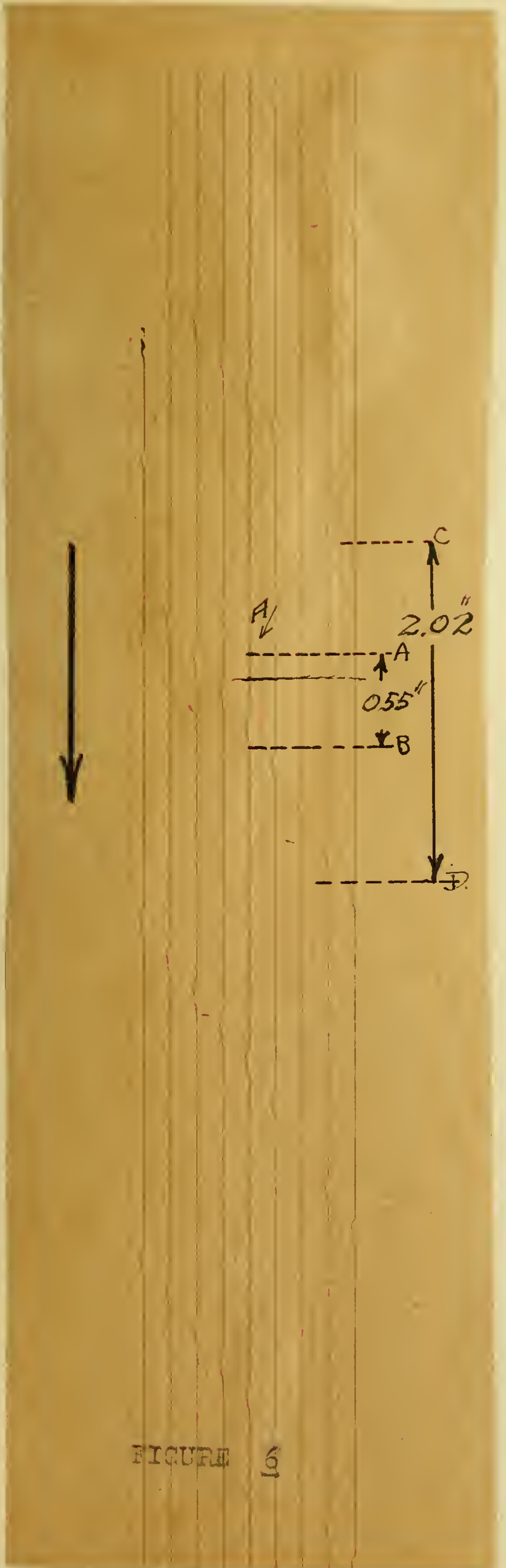


FIGURE 6

--CHRONOGRAPH RECORD--

The accompaning chronograph record shows the ratio of time of make and break to the time of one second. The drum on which the record was taken revolved in the direction indicated by the arrow.

Length "AB" includes three waves (on red line) each of which represents a "make" and a "Break" in an electric circuit. "CD" is 2.02 inches in length and, at the rate of travel of the drum, indicates one second. "AB", therefore, which is 0.55 in. in length is

$$0.55 \div 2.02 = 0.272 \text{ sec.}$$

For a single wave, therefore, the time of make and break is one third of this period, or

$$0.272 \div 3.0 = 0.0907 \text{ sec.}$$

That is, the time of make and break of the circuit containing a certain set of magnets is 0.0907 second.

----------SUMMARY----------

It would seem that a more extensive test of magnets under a greater variety of conditions should be made in order to determine the best design of magnet for any given conditions. Determinations should be made as to proportion of diameter and length of magnet, and effect of dimensions upon the inductance of the same.

As mentioned on Page 4, it would seem advantageous to construct magnets and armatures of such design as shown in Figure 2 and, by experiments upon the same, to note the effectiveness of such magnets compared to those now in use,

Thruout the tests performed upon the electro-magnets, the aim has been to determine the performance of magnets under as wide range of conditions as possible.

From Graph No. 1 it is found that a minimum current to be used in standard magnets tested should not be less than 0.15 ampere in order to obtain the greatest efficiency.

For a constant current of about .78 ampere passing thru the magnets, it was found that (See Graph No.2 Page 18) beyond 0.05 inch length of air gap, the weight lifted by the magnets was inversely proportional to the length of air gap. Below 0.05 inch air gap, a very small increase in attractive effort is obtained.

More extensive experiments might be made to investigate the operation of the switch for various ratios of make to break.

---------SUGGESTIONS-------

The following suggestions, then, as to possible improvements on the electro-magnet have occurred to the writers.

First: A design of armature and core similar to that shown on Page 5 would seem better than that in use at the present time. The same power of magnetic attraction would be available for less current.

Second: A further reduction in the length of magnet would be of advantage.

Third: The use of an auxiliary short circuited coil as previously explained would be of advantage in the reduction of sparking.

Besides these points mentioned, indications have been made as to various experiments that ought to be made in order to determine the best design of magnets for use in the automatic telephone.